Stagnation-Point Radiative Heat Fluxes in Neptune Aero-capture

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- Background
- Review of a new ionization model for H+He.
- Application to Neptune entry.
- Concluding remarks.

Background – 1
chronology

- Neptune and Triton are closest to Kuiper Belt, which may hold clues to extra-terrestrial origin of life.
- Would like to insert an orbiter around Neptune that crosses the orbit of Triton.
- Several NASA proposals to explore Neptune and Triton.
- Minimum-energy trajectory takes too long. Fast mission using swing-by needed.
- Triton rotates retrograde. Results in 30 km/s entry speed. Aero-capture is needed.
- Neptune's atmosphere: 81%H_2, 18.5%He, 1.5%CH_4.
- Hollis et al (2004) examined the heating rates, predicted q_{conv}=4 kW/cm^2, q_{rad}=1 kW/cm^2(part of q_{rad} converted to q_{conv})

Background – 2
Scientific issues

- Ionization rate of H will affect radiation. Ionization rate of H is dictated mostly by the birth of the first electrons by H+H collisions. The birth of first electrons is influenced by absorption of Lyman-a radiation.

- Ionization rate in H+He mixture was measured by Leibowitz (1973) and Livingston and Poon (1976) in a shock tube, from which the H+H ionization cross section can be determined. There is a factor of 4 difference in rates between the two results.

- Bogdanoff and Park (2002) tried to reproduce the earlier data in a shock tube, and failed.

- Park (2010) analyzed Livingston-Poon data, accounting for Lyman-a absorption, and developed a new reaction model for H+He mixture (H+H and H+He ionization).

- H_2 dissociation and vibrational-rotational excitation problem solved by Kim et al(2009).

- Shock tube experiment of Hyun et al(2009) shows that H hitting carbon surface does not produce CH.

- Present work applies these new model to calculate the stagnation-point radiative heat flux at the edge of boundary layer. (The edge value is the controlling value.)
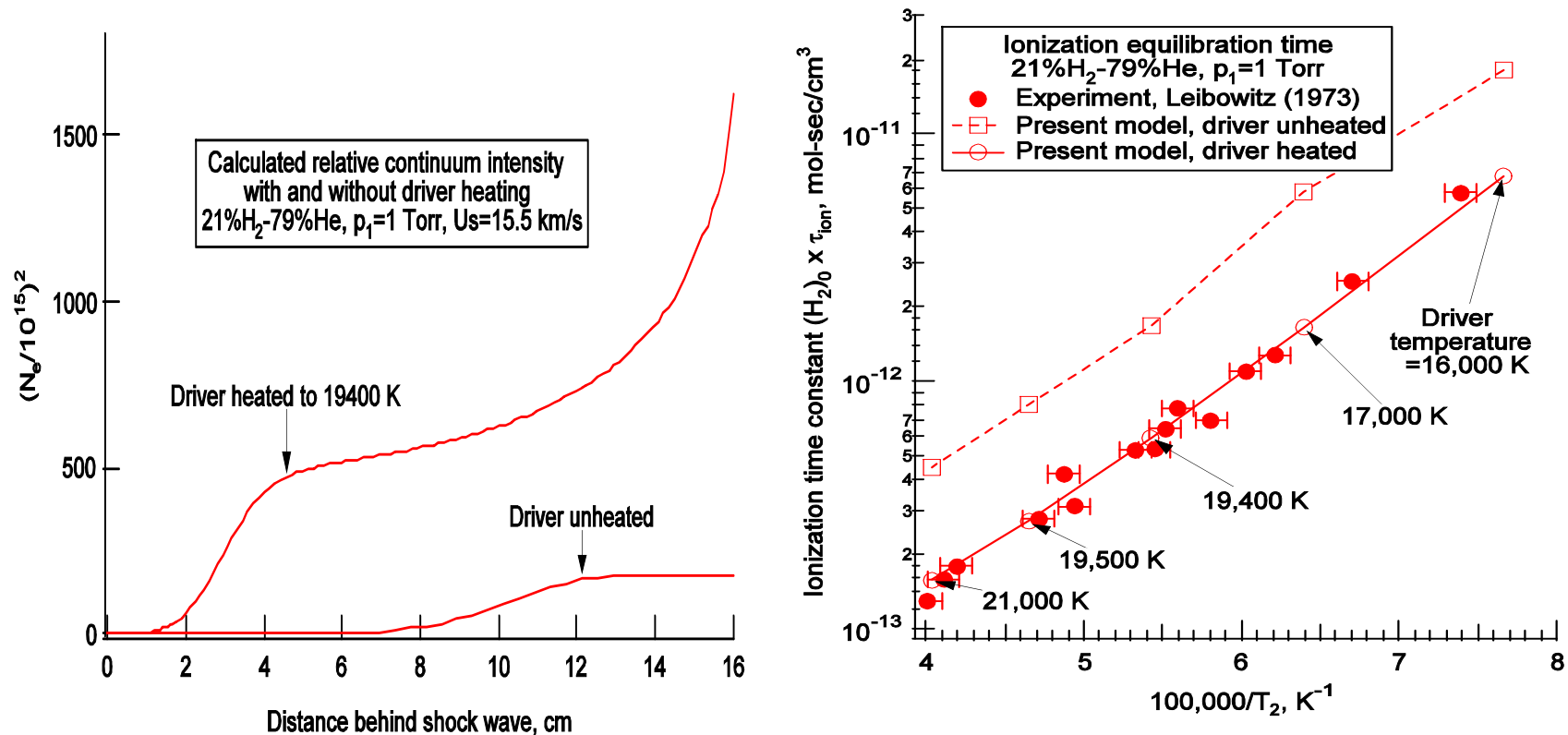
Review of Park's new H+He ionization model (2010)
based on Livingston and Poon's shock tube data

- **Reproduces the equilibrium distances and peak electron densities in H+He mixture obtained by Livingston and Poon (1976) in a shock tube. (agreement imperfect)**
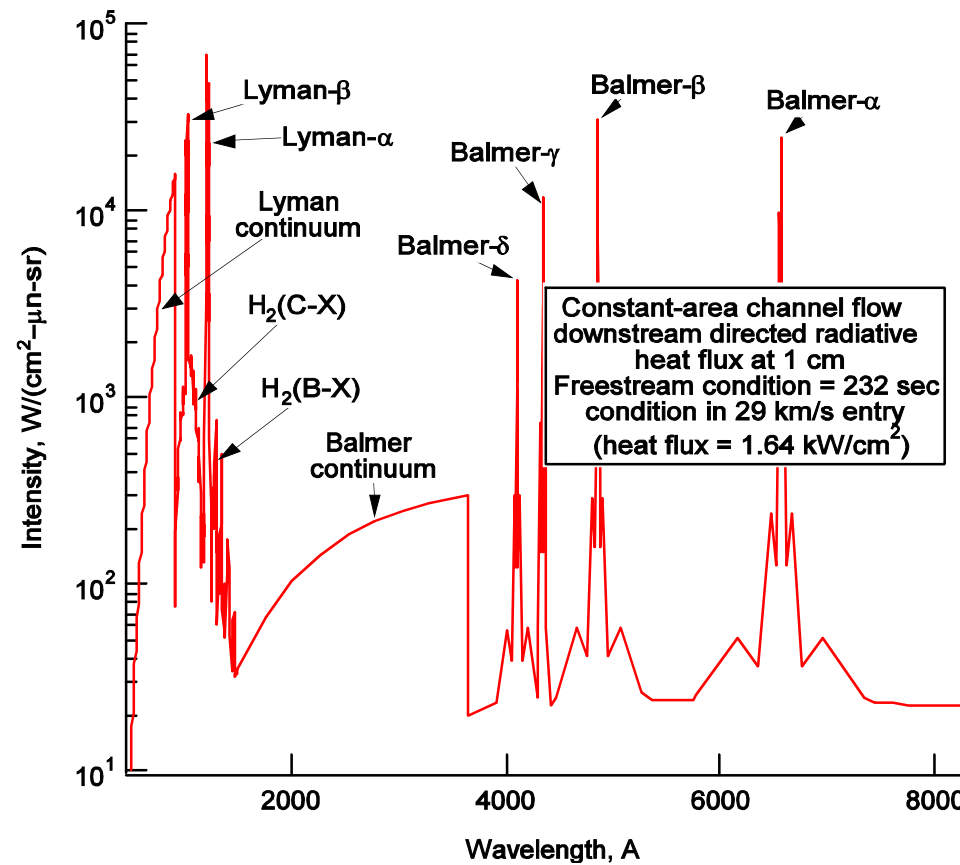- **Note that the peak electron density is higher than the Rankine-Hugoniot equilibrium value.**
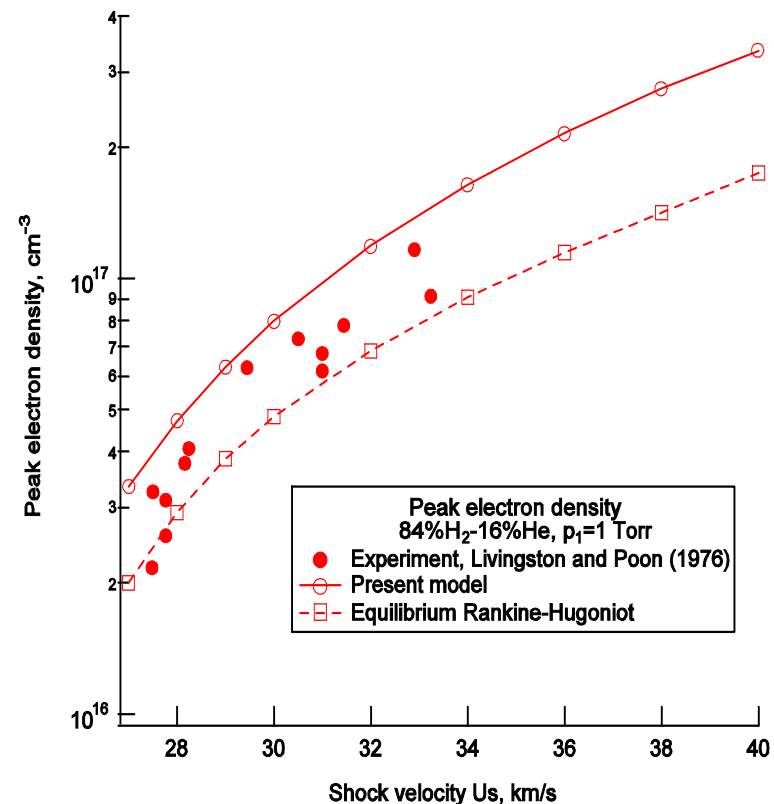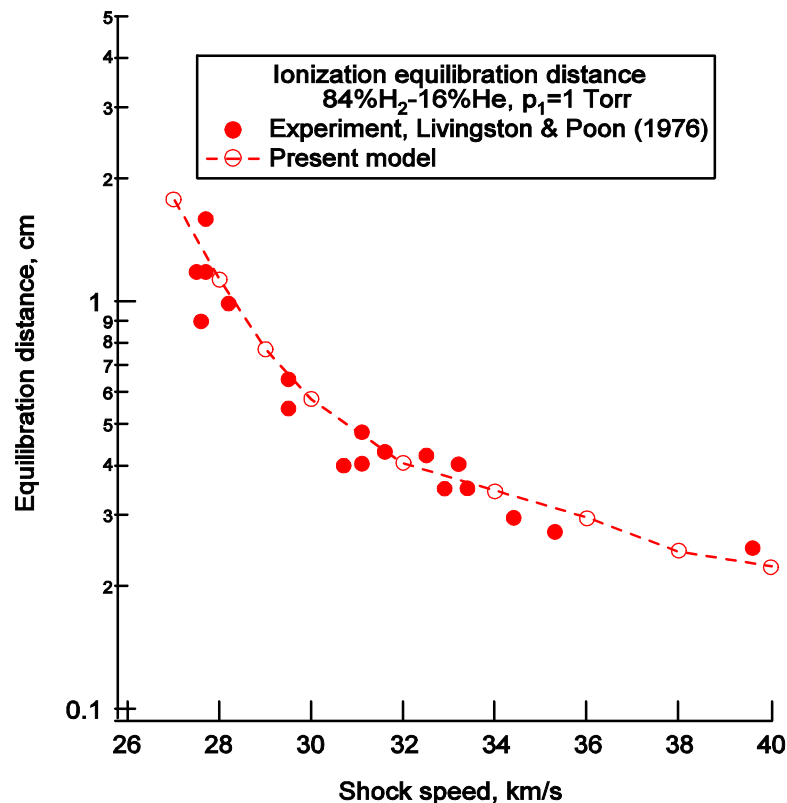
Reason for discrepancy between Leibowitz (1973) and Livingston and Poon (1976) is explained

• The irradiation from driver gas in Leibowitz's experiment caused four times faster ionization.

Calculated relative continuum intensity with and without driver heating $21\%H_2$-$79\%He$, $p_1=1$ Torr, $U_s=15.5$ km/s

Driver heated to 19400 K

Driver unheated

Ionization equilibration time $21\%H_2$-$79\%He$, $p_1=1$ Torr
● Experiment, Leibowitz (1973)
⊡ Present model, driver unheated
⊖ Present model, driver heated

Driver temperature = 16,000 K

17,000 K

19,400 K

19,500 K

21,000 K

Radiation spectrum

- **Significant contribution for H_2 B-X and C-X in vacuum ultra-violet.**

Application to Neptune Entry
assuming a 1-D constant area channel flow of 1 cm long

- **Radiative heat transfer rate is about 1.6 times higher than the values obtained by Hollis et al (2002). Heat load is 1/5 of that to Galileo Probe.**
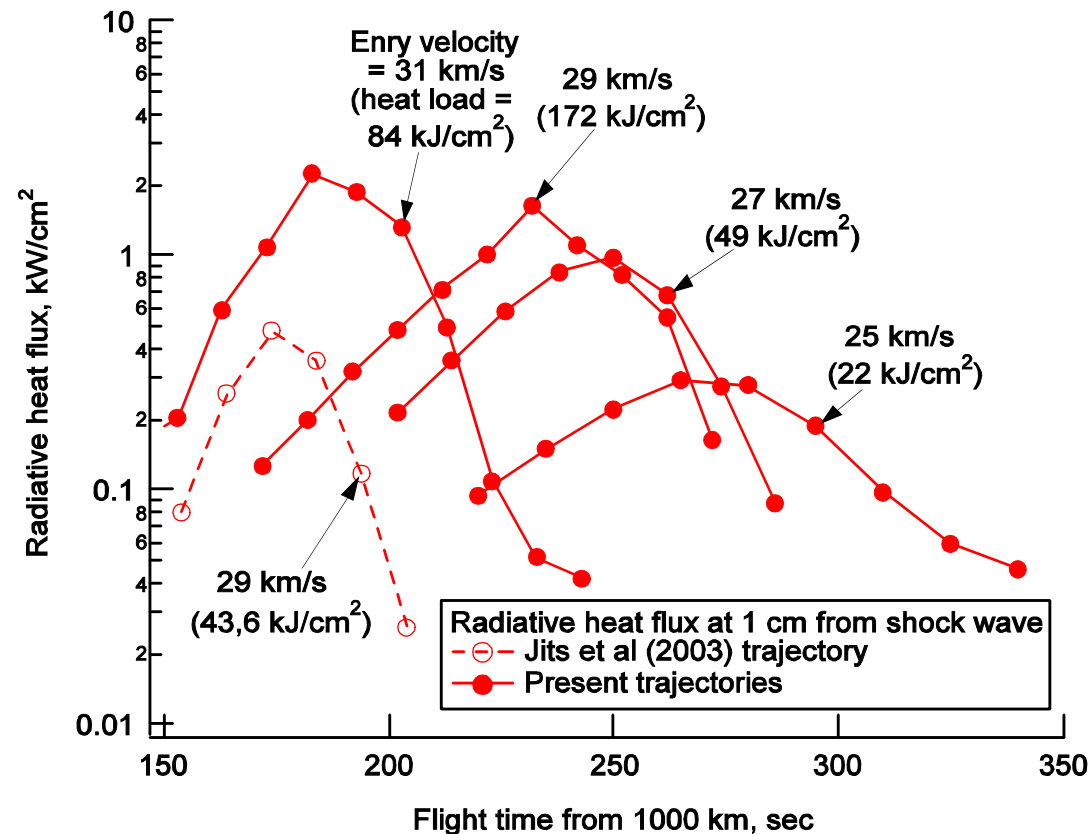
Concluding Remarks

- A new ionization model was developed for H+He mixture.
- The model leads to radiative heat transfer rates higher than those by earlier model.
- The role of methane (carbon) on radiation needs to be investigated.
- Shock tube experiment with H+He+CH$_4$ mixture is desirable, but how to do is not known.
- CFD needs to be done. Calculation of Lyman-α absorption will be a challenge.
- Overall aerothermodynamics of Neptune entry is very difficult, primarily because of lack of experiment.